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FORCE TESTS ON A SEPARABLE-NOSE CREW ESCAPE CAPSULE WITH COLD FLOW ROCKET JET SIMULATION AT MACH NUMBERS 1.5 THROUGH 6

Leroy M. Jenke, Jerry H. Jones, and A. W. Myers

ARO, Inc.

April 1966

VON KÁRMÁN GAS DYNAMICS FACILITY
ARNOLD ENGINEERING DEVELOPMENT CENTER
AIR FORCE SYSTEMS COMMAND
ARNOLD AIR FORCE STATION, TENNESSEE

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ROCKET JET SIMULATION AT MACH
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Arnold Engineering Development Center
Air Force Systems Command
Arnold Air Force Station, Tennessee

The last sentence of the text, on page 4, should read:

This reversal of the data slopes is attributed to the reduced effectiveness of the lower booms in roll caused by being submerged in the jet plume which is, of course, greater at the higher p_c/p_∞ values.

AEDC-TR-66-74

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ARO, Inc.

FOREWORD

The work reported herein was done at the request of the Air Force Flight Dynamics Laboratory (AFFDL), Air Force Systems Command (AFSC), under Program Element 62405364, Project 1362.

The results of tests presented were obtained by ARO, Inc. (a subsidiary of Sverdrup & Parcel and Associates, Inc.), contract operator of the Arnold Engineering Development Center (AEDC), AFSC, Arnold Air Force Station, Tennessee, under Contract AF 40(600)-1200. The tests were conducted intermittently within the period from June 2, 1965, to January 17, 1966, under ARO Project No. VT0508. The manuscript was submitted for publication on March 15, 1966.

This technical report has been reviewed and is approved.

Donald E. Beitsch
Major, USAF
AF Representative, VKF
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Jean A. Jack
Colonel, USAF
DCS/Test

ABSTRACT

Static force tests were conducted in the 40-in. supersonic tunnel of the von Kármán Gas Dynamics Facility on a separable-nose crew escape capsule having cold flow simulation of the separation rocket jet plume. Data were obtained at Mach numbers from 1.5 to 6 at angles of attack from -30 to 30 deg and angles of sideslip from -15 to 15 deg. Reynolds number, based on a model length of 18.1 in., ranged from 1.36×10^6 to 12.3×10^6. Selected results are presented showing the effects of the rocket exhaust jet on the static stability and drag characteristics of the vehicle.

CONTENTS

ILLUSTRATIONS

TABLE

NOMENCLATURE

A	Reference area (cross-sectional area at separation bulkhead), 22.608 sq in.
C_D	Drag coefficient, drag/$q_\infty A$
C_L	Lift coefficient, lift/$q_\infty A$
C_ℓ	Rolling-moment coefficient, rolling moment/$q_\infty A\ell$
C_m	Pitching-moment coefficient, pitching moment/$q_\infty A\ell$
C_n	Yawing-moment coefficient, yawing moment/$q_\infty A\ell$
C_Y	Side-force coefficient, side force/$q_\infty A$
ℓ	Reference length (distance from nose to separation bulkhead), 16.5 in.
M_j	Jet nozzle exit Mach number
M_∞	Free-stream Mach number
p_c	Jet chamber pressure, psia
p_o	Tunnel stilling chamber pressure, psia
p_∞	Free-stream static pressure, psia
q_∞	Free-stream dynamic pressure, psia
Re	Reynolds number
T_o	Tunnel stilling chamber temperature, °F
α	Angle of attack, deg
β	Angle of sideslip, deg
γ	Ratio of specific heats

NOTE: Force and moment coefficients are in the stability axis system.

SECTION I
INTRODUCTION

These tests constitute Phase I of a wind tunnel test program requested by the Flight Recovery Group (FDFR), AFFDL to provide data for investigating crew escape systems for high-speed flight vehicles. In this phase, tests were made on a separable-nose escape capsule incorporating several trim control surfaces, with cold flow simulation of the exhaust plume from the escape rocket at various altitudes. In later tests the aerodynamic characteristics of the separable-nose capsule in proximity to the parent body (fuselage) and other crew escape capsule configurations will be investigated.

Static force data were obtained at Mach numbers from 1.5 to 6 at angles of attack from -30 to 30 deg and angles of sideslip from -15 to 15 deg. Reynolds number, based on a model length of 18.1 in., ranged from 1.36×10^6 to 12.3×10^6.

SECTION II
APPARATUS

2.1 WIND TUNNEL

The 40-in. supersonic tunnel (Gas Dynamic Wind Tunnel, Supersonic (A)) is a continuous, closed-circuit, variable density wind tunnel with an automatically driven, flexible-plate-type nozzle and a 40- by 40-in. test section. The tunnel operates at Mach numbers from 1.5 to 6 at maximum stagnation pressures from 29 to 200 psia, respectively, and stagnation temperatures up to 300°F (M_∞ = 6). Minimum operating pressures are about one-tenth of the maximum at each Mach number.

2.2 MODEL

The 1/10-scale, separable-nose escape capsule model (Figs. 1 through 4) was provided by AFFDL and consisted of the nose and canopy section of the F-104 aircraft. The capsule had three wedge-shaped stabilizing booms extending to the rear. These booms (Fig. 1b) were positioned 120 deg apart, and the upper boom could be fitted with three

different trim tab configurations (Figs. 1a and c). The trim tab for configuration 1 was used in combination with two flat plate tabs of different size for configurations 2 and 3 (Figs. 1c and 3). The cold air jet nozzle was positioned in a cutout on the lower aft portion of the model (Fig. 2) and was attached to the sting such that the model was isolated from the jet reaction force.

Details of the nozzle are given in Fig. 1d, and the procedures used to calculate the required nozzle dimensions and chamber pressures for simulation of the full-scale jet plume shape at various altitudes over the Mach number range are given in the Appendix.

2.3 INSTRUMENTATION

Model force measurements were made with a six-component, moment-type, strain-gage balance supplied and calibrated by the von Kármán Gas Dynamics Facility. Prior to the test, combined static loadings were applied to the balance which simulated the range of model loadings anticipated for the test. The ranges of uncertainties listed below correspond to the differences between the applied loads and the values calculated by the balance equations used in the final data reduction.

Balance Component	Design Load	Range of Static Loadings	Range of Uncertainties
Normal force, lb	250	0 to 250	±0.4 to ±0.75
Pitching moment, in./lb	1234	0 to 365	±4.7
Side force, lb	125	0 to 125	±0.3 to ±0.6
Yawing moment, in./lb	617	0 to 185	±2.0
Rolling moment, in./lb	60	16 to 64	±0.4
Axial force, lb	300	100 to 300	±0.25 to ±1.25

Two jet chamber pressure measurements were made using transducers calibrated for a full-scale range of 1000 psia, which are considered accurate to within 1 percent of full scale.

Base pressures were measured with transducers of 15-, 5-, and 1-psid capacity, referenced to a near vacuum, which are considered accurate to within 0.25 percent of full scale of the transducer capacity. A base drag correction was made for the balance cavity area only.

A summary of the test conditions is given in Table I.

SECTION III
RESULTS AND DISCUSSION

Static longitudinal stability and drag characteristics, jet on and jet off, are presented in Fig. 5 for Mach numbers 2, 4, and 6. All configurations were longitudinally stable. As would be expected, because of its location far aft of the moment reference, the primary effect of increasing the trim tab area was to produce a positive increment in pitching moment. The effect was the same at all Mach numbers, jet on and jet off, although the tab effectiveness decreased at high positive angles of attack because of the shielding effect of the capsule.

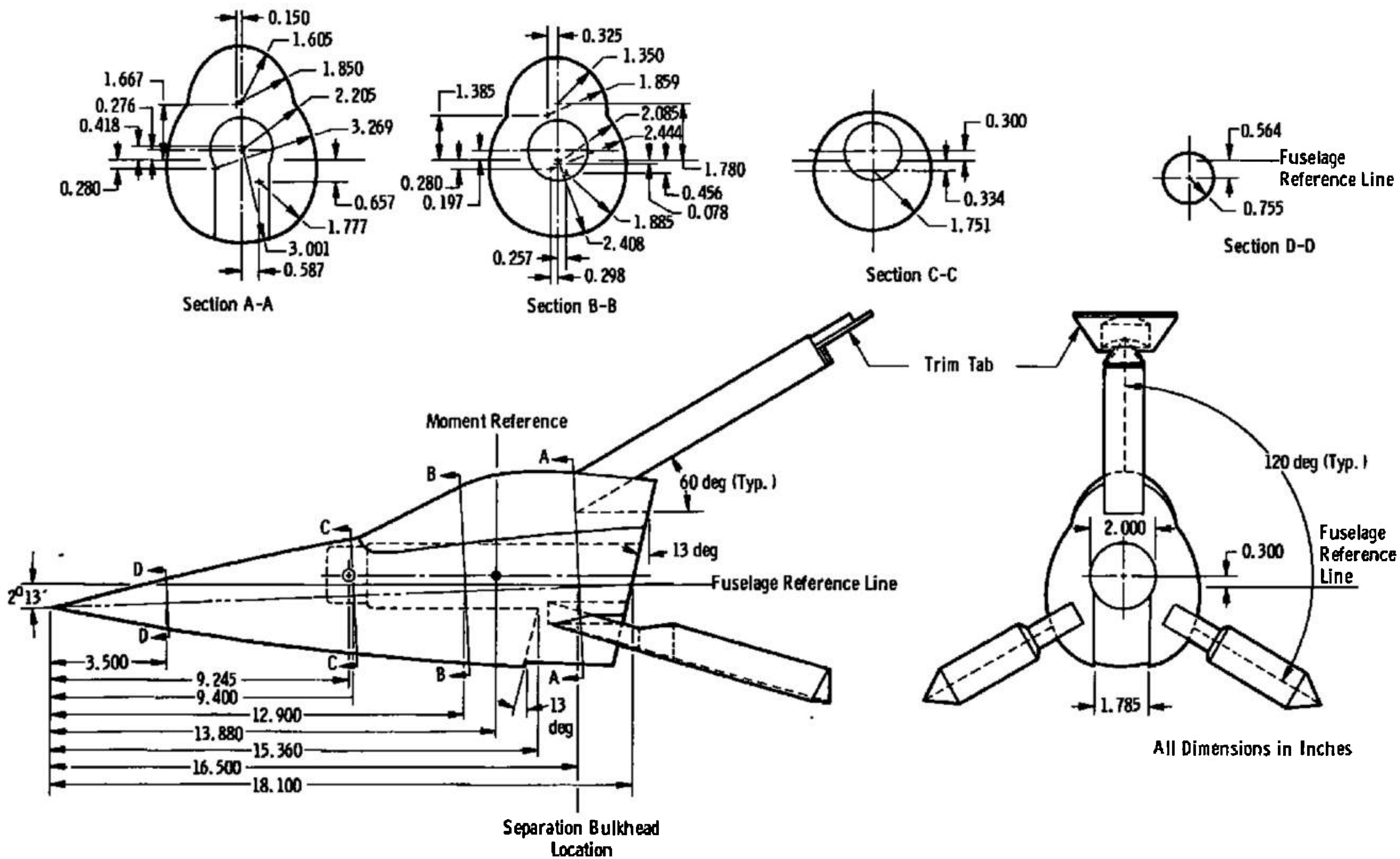
The results (Fig. 5) also show that the effect of the jet flow was to increase the lift and nose-down pitching moment. This follows from the increase in pressure obtained on the aft, lower surfaces of the model with the jet on. Because of the positive increase in lift with jet on, there was a general shift in level of the C_L versus C_D curves, although drag was decreased somewhat by the pressure increase in the model base region.

Included in Fig. 5 are data showing the effects of decreasing the jet/chamber pressure ratio, p_c/p_∞, at $M_\infty = 2$ and 4 and of increasing p_c/p_∞ at $M_\infty = 6$. The effect on lift and drag was as expected, that is, the jet effects increased as p_c/p_∞ was increased. Pitching moment was influenced greatly by the extent of the flow separation induced by the jet plume. The results for $M_\infty = 6$ (Fig. 5c) show that, although lift increased with p_c/p_∞ increase, the nose-down pitching moment was decreased because of an increase in the extent of the separated flow region. This change in the extent of the separated flow can be seen in the schlieren photographs of Fig. 6.

Directional and lateral stability characteristics for the three configurations are presented in Fig. 7. All configurations were directionally stable at all Mach numbers, and changing the trim tab had no effect on these characteristics. There was little or no effect of the jet flow on side force and yawing moment, but the jet effect on rolling moment was significant. Changing the trim tab also had an effect on roll, and it can be seen that a Mach number effect was also present for both jet off and jet on conditions by the change in slope of the curve (C_ℓ versus β).

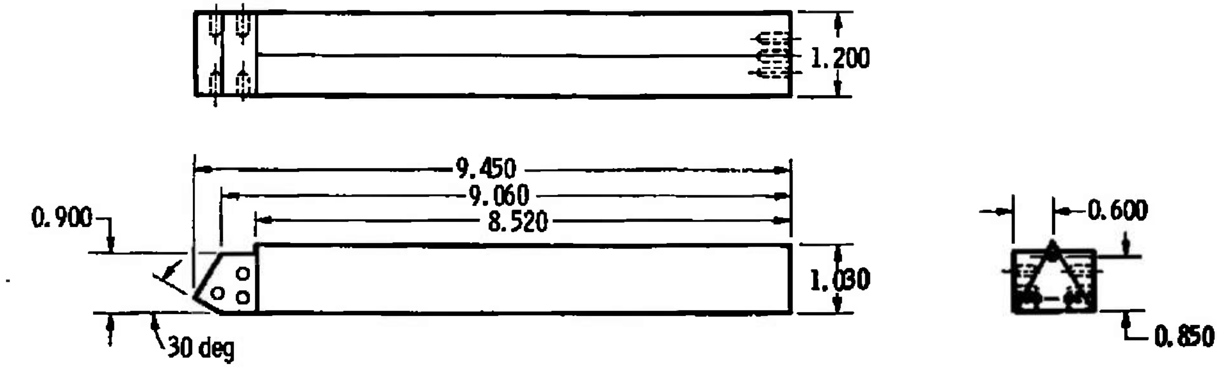
In order to show these trends more clearly, the rolling-moment characteristics for Mach numbers from 2 to 6 are presented in Fig. 8. Data are given for high altitude conditions (i.e., low Reynolds number and high p_c/p_∞) in Fig. 8a and for low altitude conditions (high Reynolds

number and low p_c/p_∞) in Fig. 8b. As can be seen, there is a continuous change in the data slopes as Mach number increases, which is caused by changing local flow conditions on the upper and lower trailing booms. The data trends are the same for both altitude conditions and jet off, but with the jet on a reversal in trend is obtained for the high altitude condition (high p_c/p_∞) at each Mach number. This reversal of booms in roll caused by being submerged in the jet plume which is, of course, greater at the higher p_c/p_∞ values.



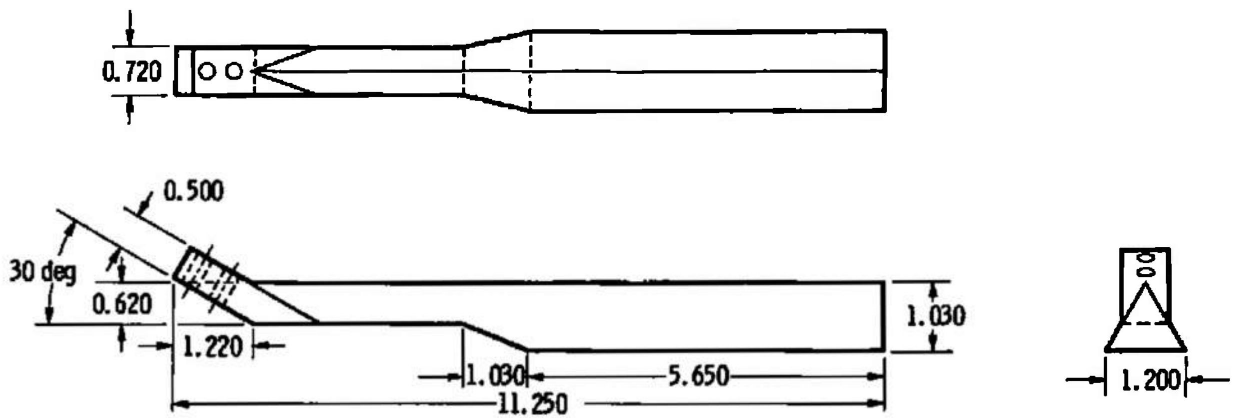
a. Capsule Details (Config. 3)

Fig. 1 Model Details



Upper Boom

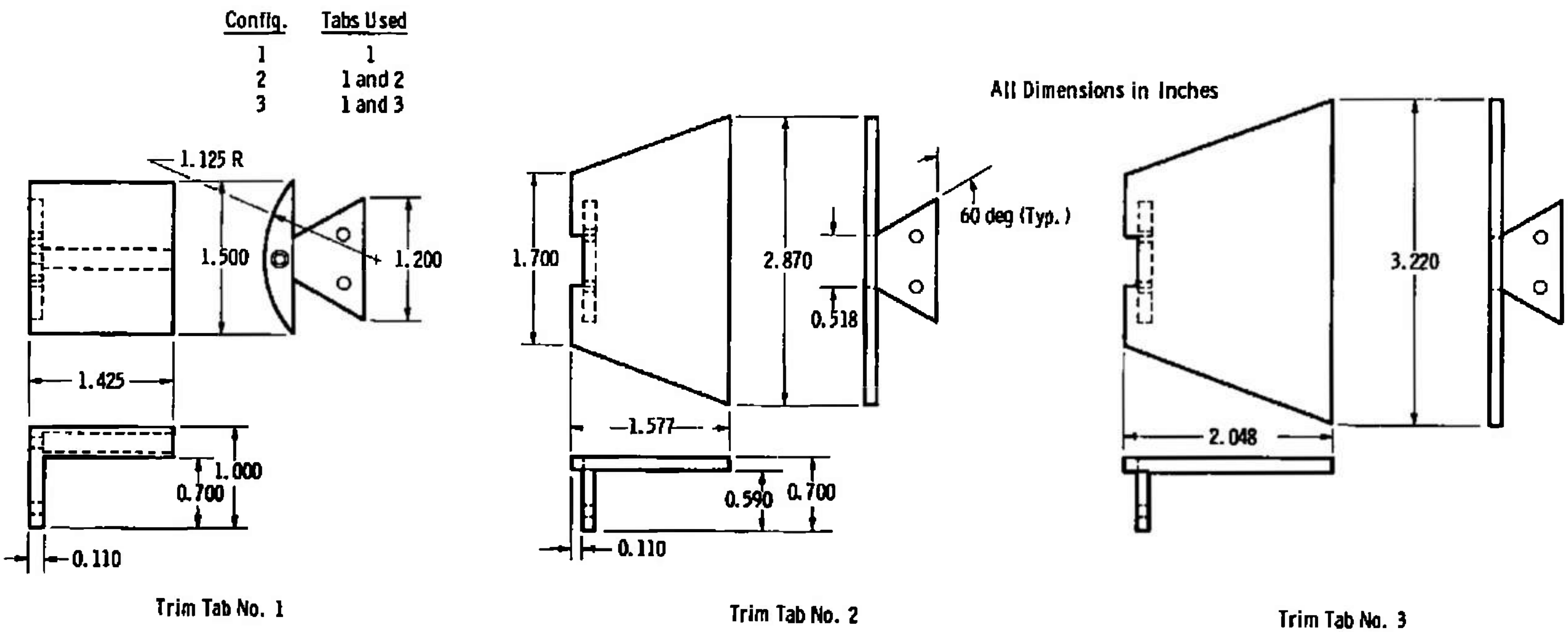
All Dimensions in Inches



Lower Boom (2 Required)

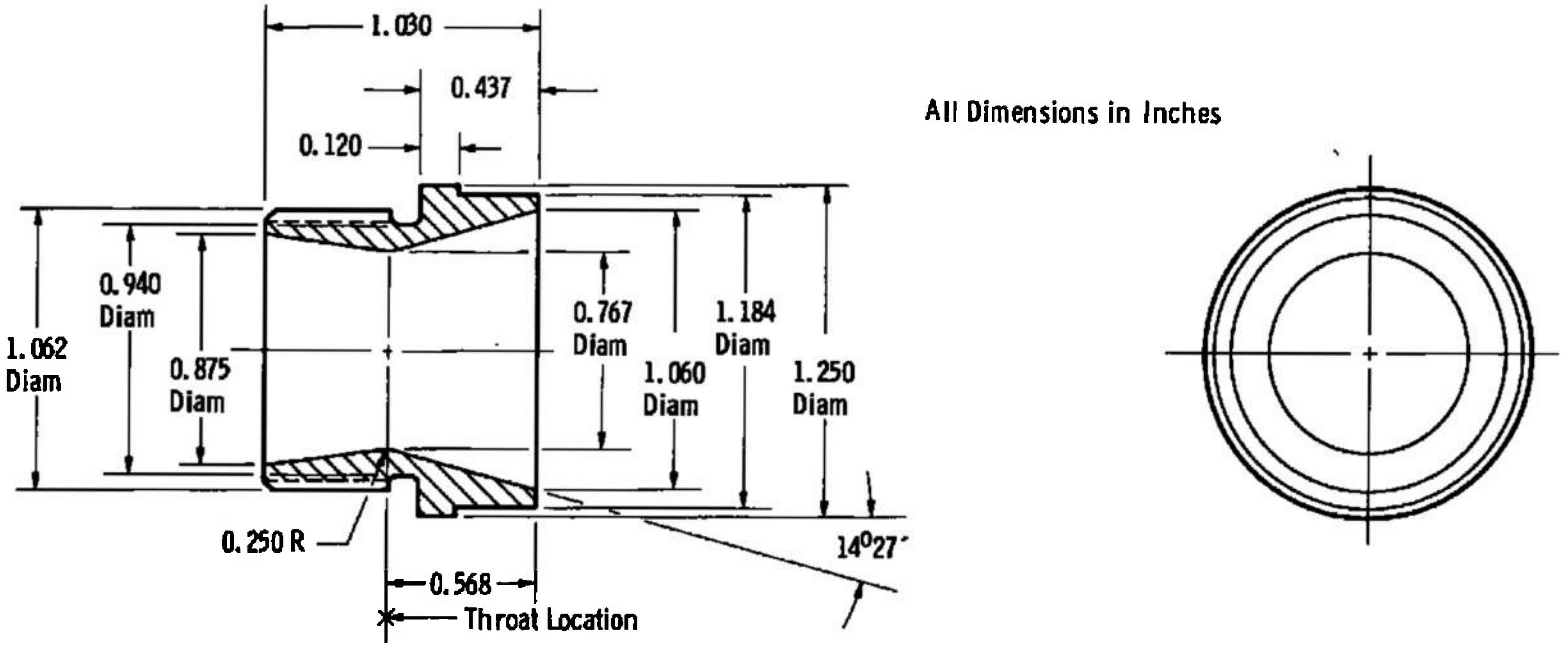
b. Trailing Boom Details

Fig. 1 Continued



c. Trim Tab Details

Fig. 1 Continued



d. Nozzle Details

Fig. 1 Concluded

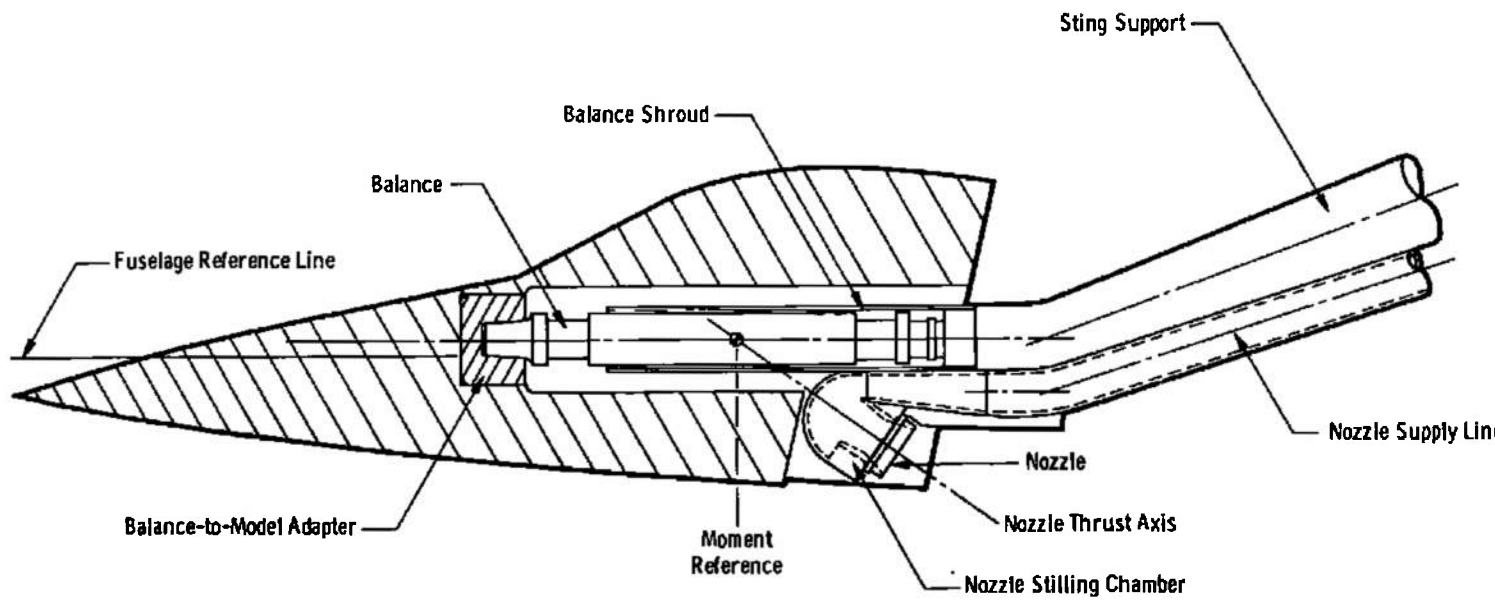
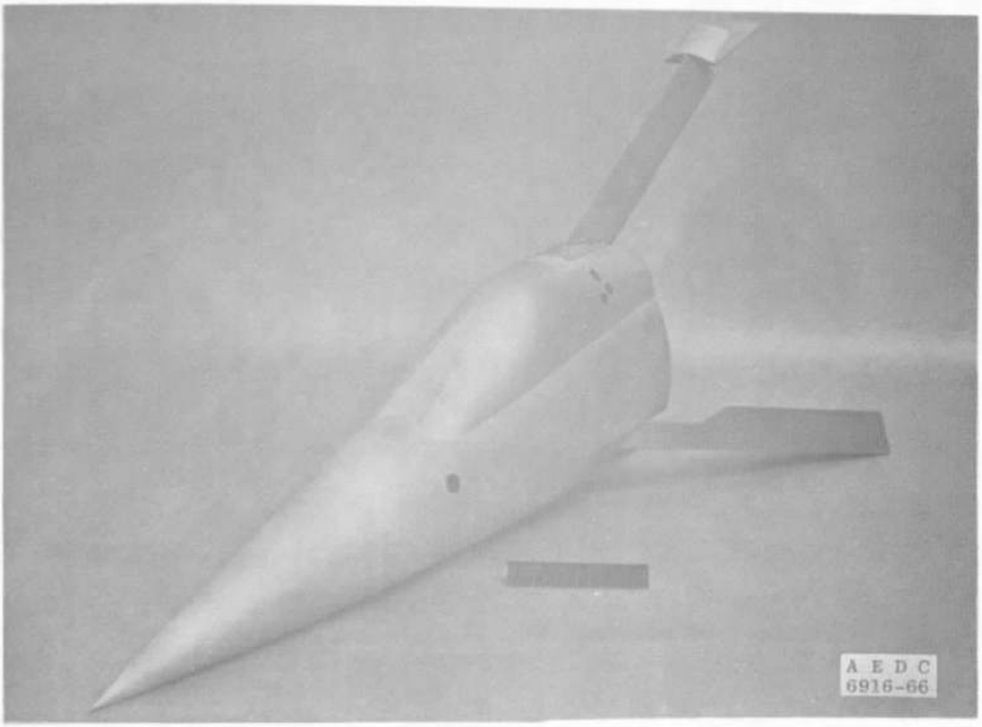
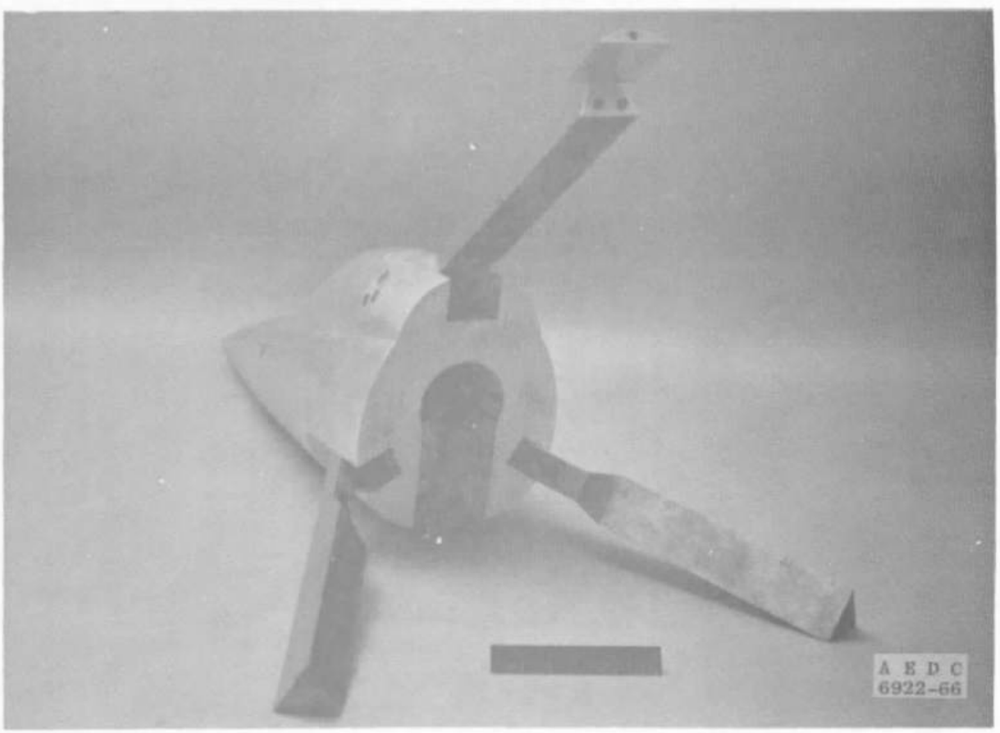


Fig. 2 Model Installation Sketch



Configuration 3



Configuration 1

Fig. 3 Model Photographs

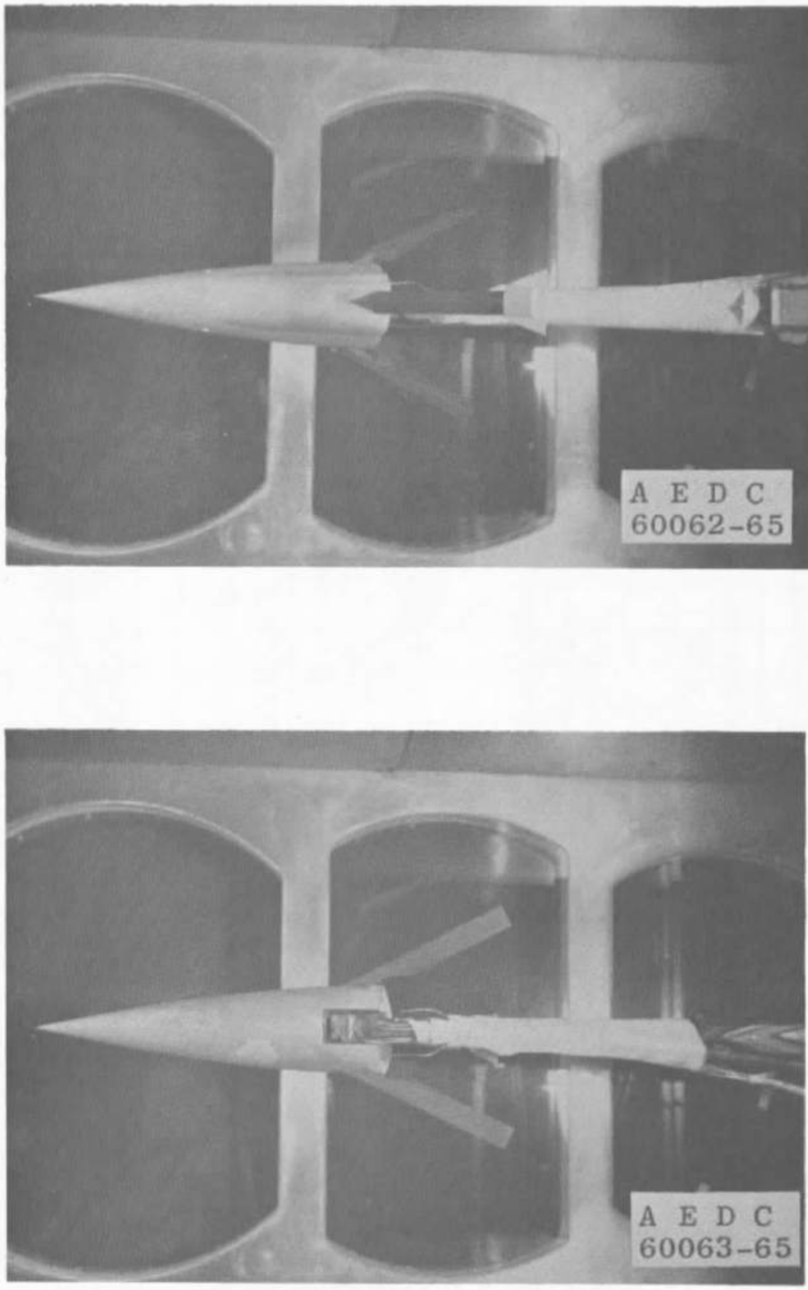
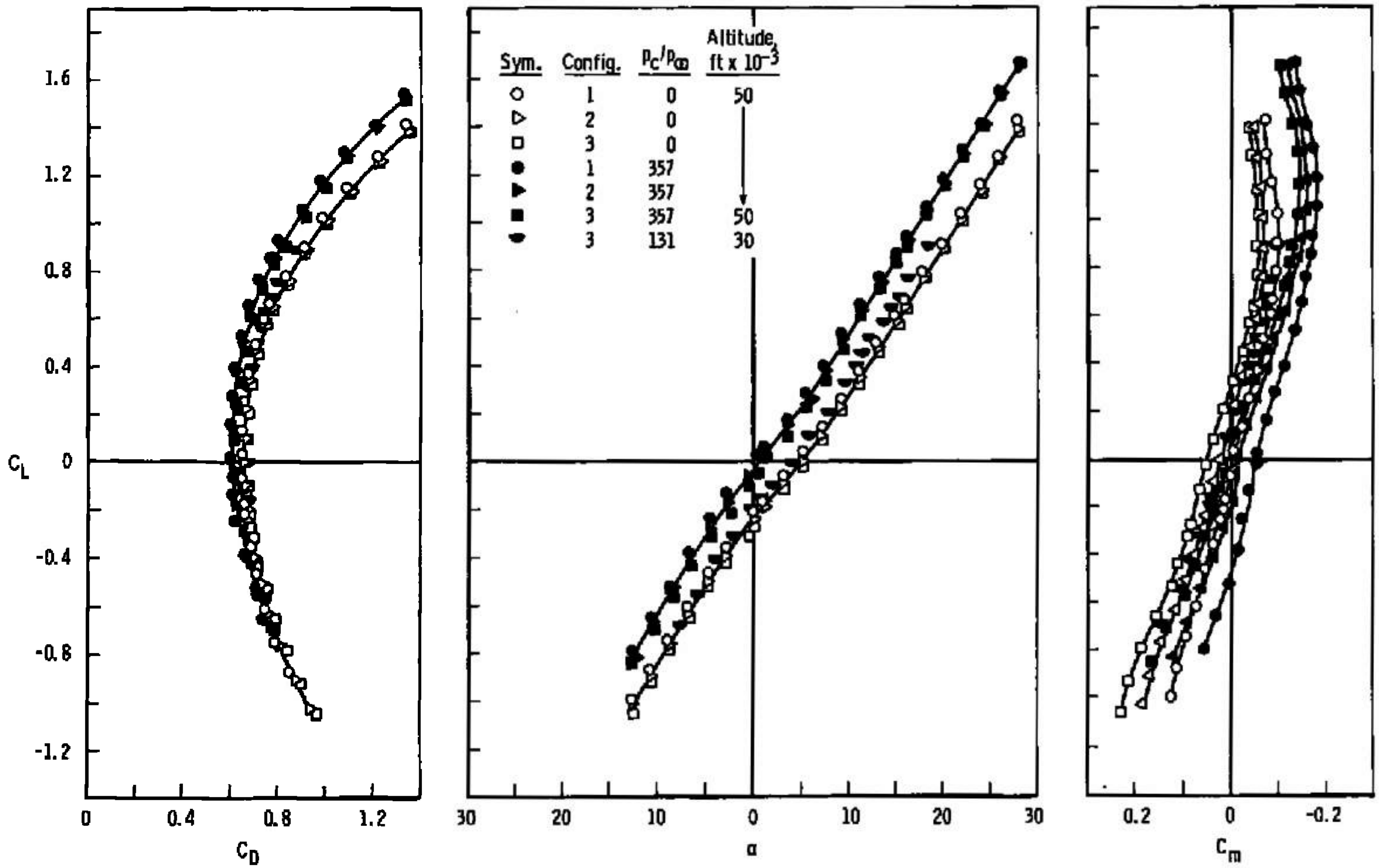
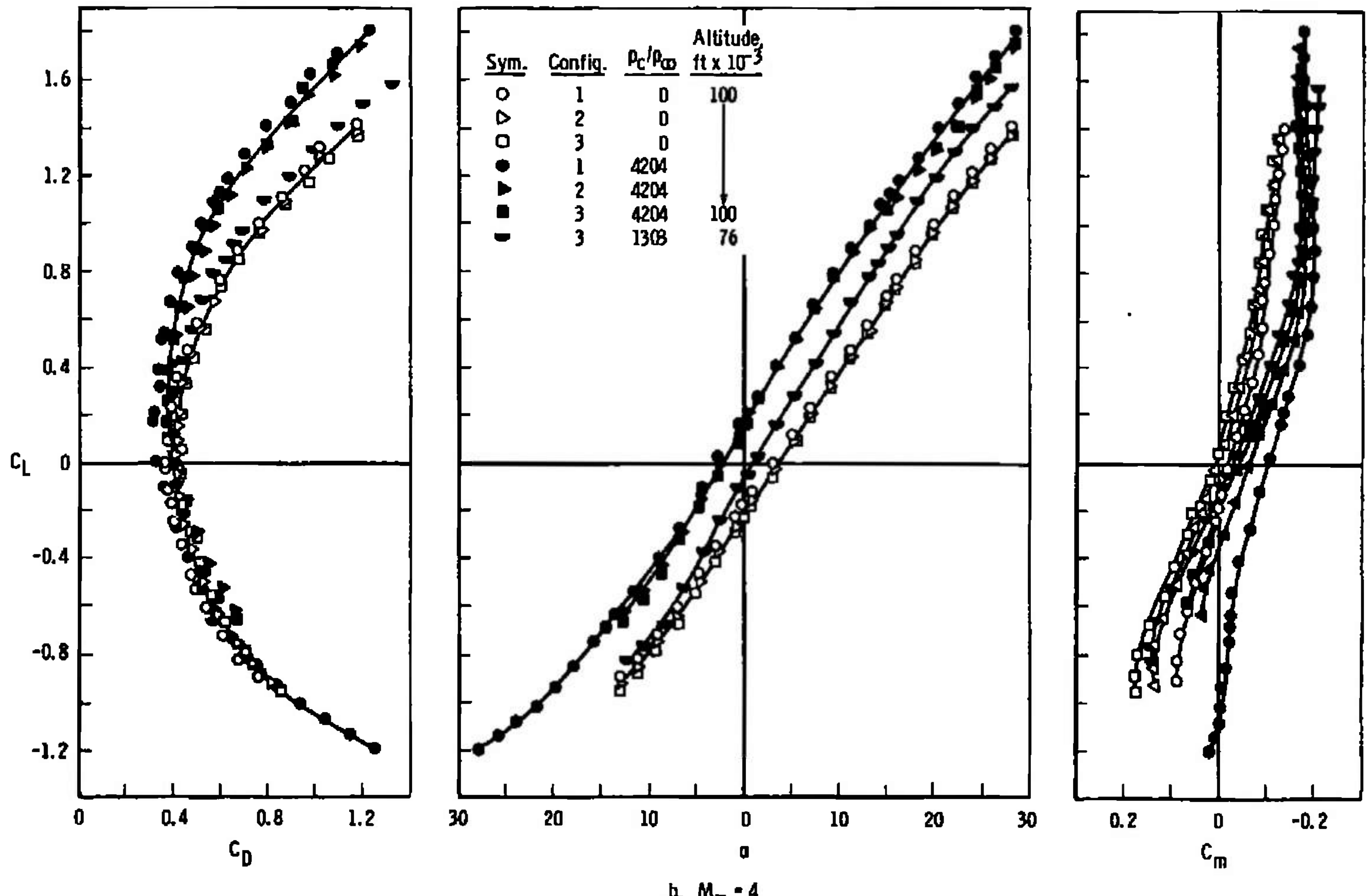


Fig. 4 Configuration 3 Installation Photographs



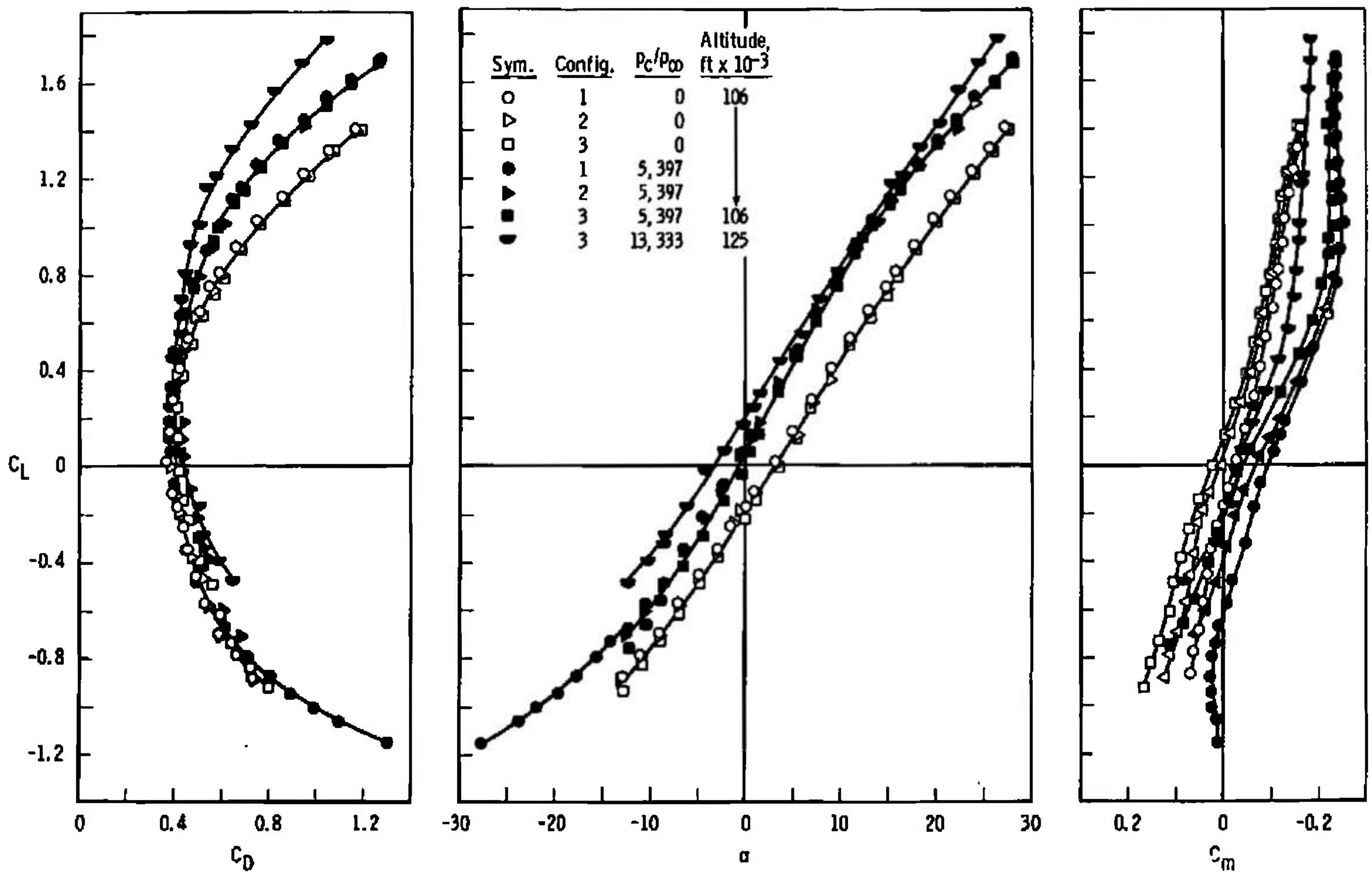
a. $M_\infty \approx 2$

Fig. 5 Static Longitudinal Stability and Drag Characteristics



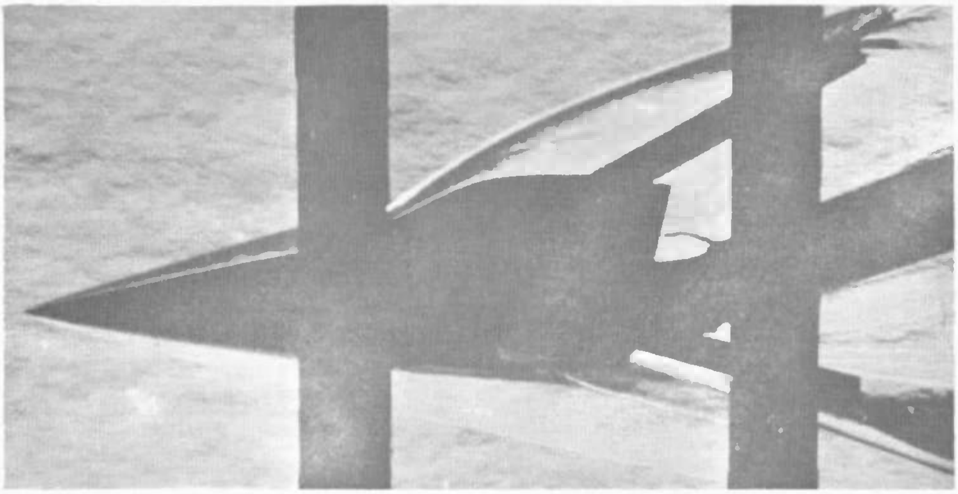
b. $M_\infty = 4$

Fig. 5 Continued

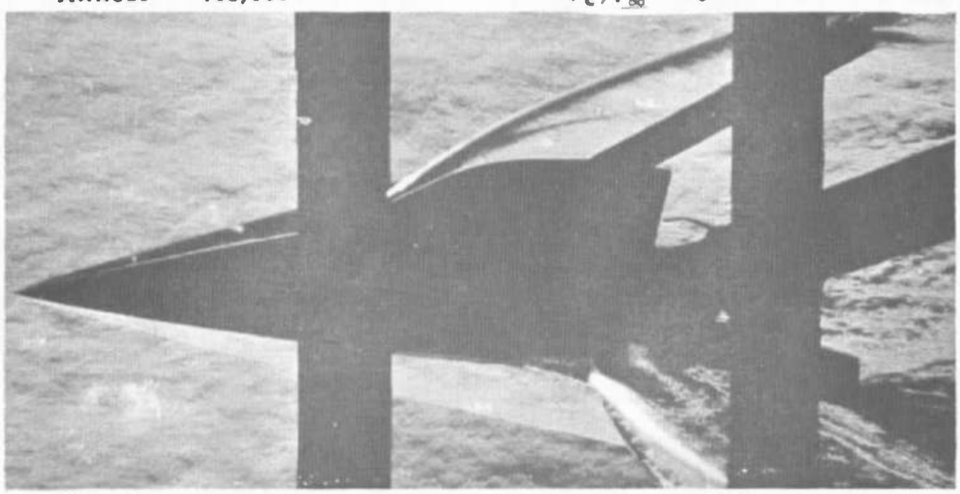


c. $M_\infty = 6$

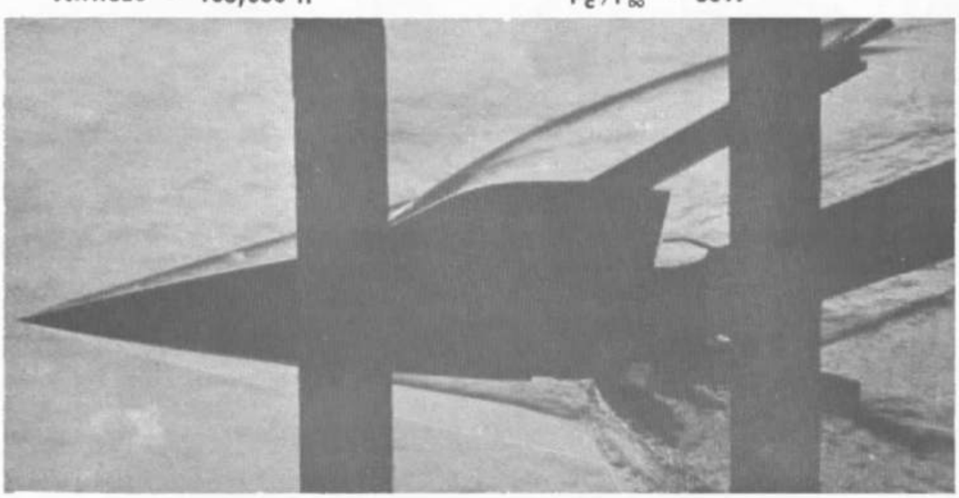
Fig. 5 Concluded



Altitude = 106,000 ft $\qquad$ $p_c/p_\infty = 0$

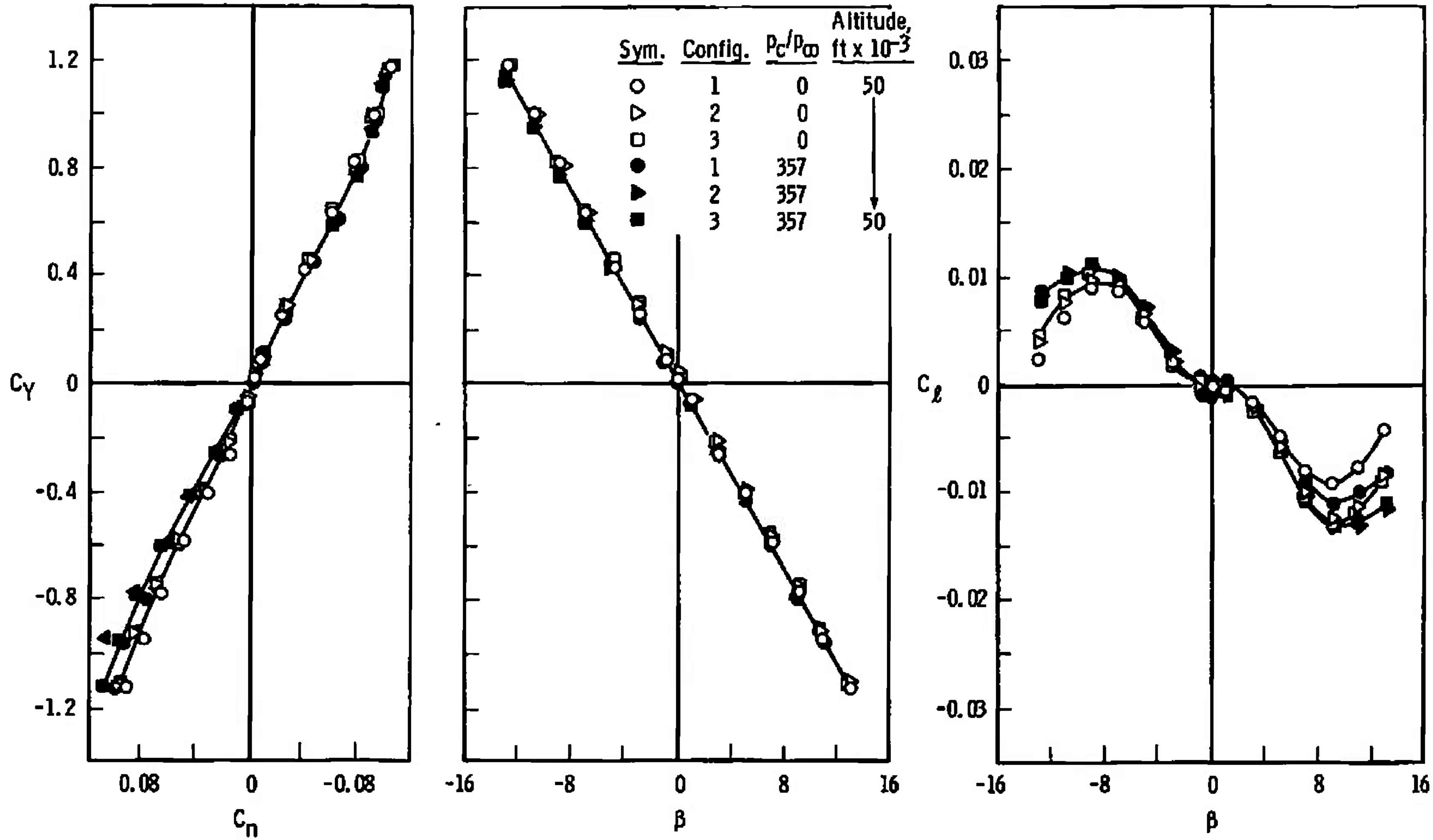


Altitude = 106,000 ft $\qquad$ $p_c/p_\infty = 5397$



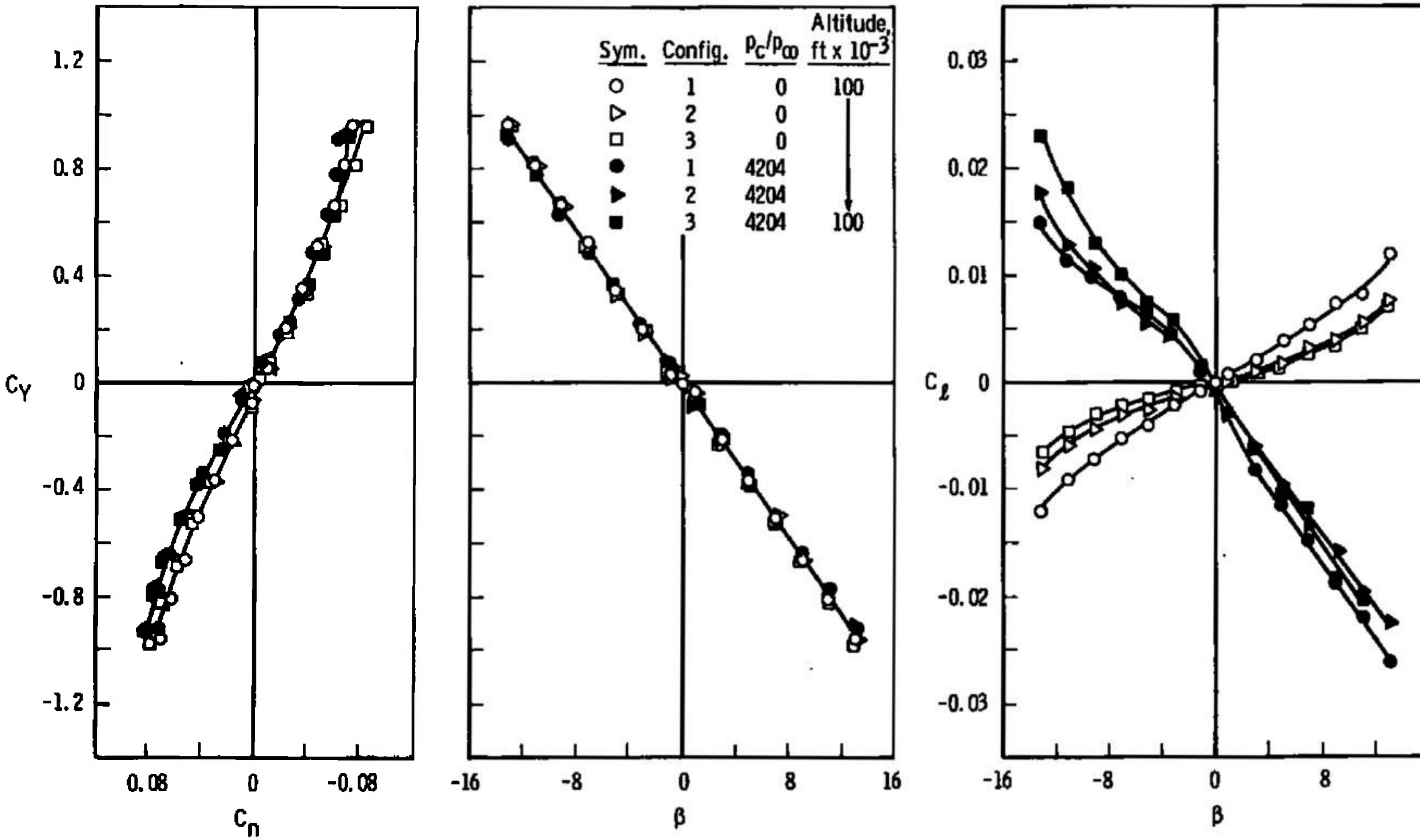
Altitude = 125,000 ft $\qquad$ $p_c/p_\infty = 13,333$

Fig. 6 Schlieren Photographs, $M_\infty = 6$, $\alpha = 0$



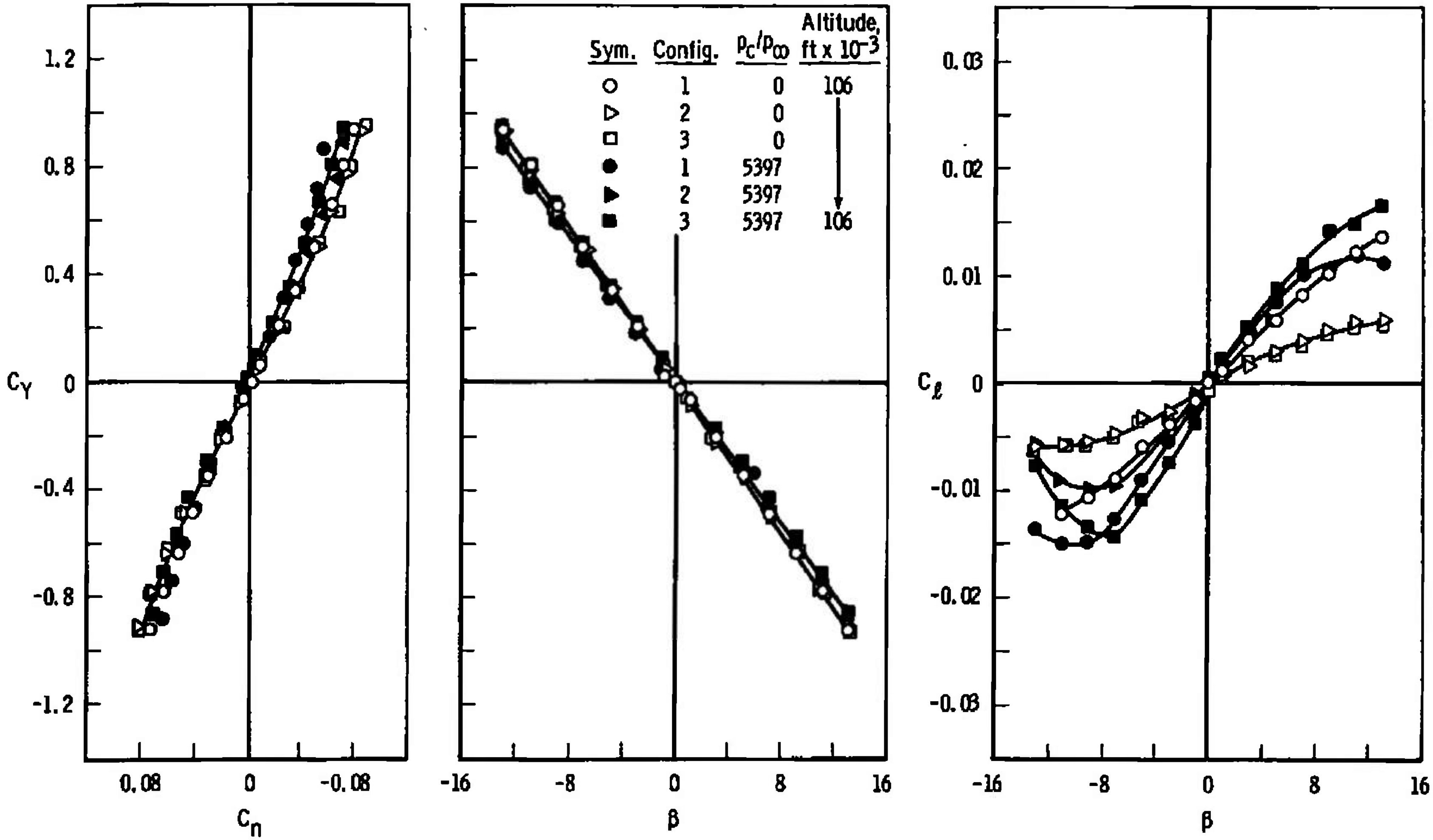
a. $M_\infty = 2$

Fig. 7 Directional and Lateral Stability Characteristics, $\alpha = 0$



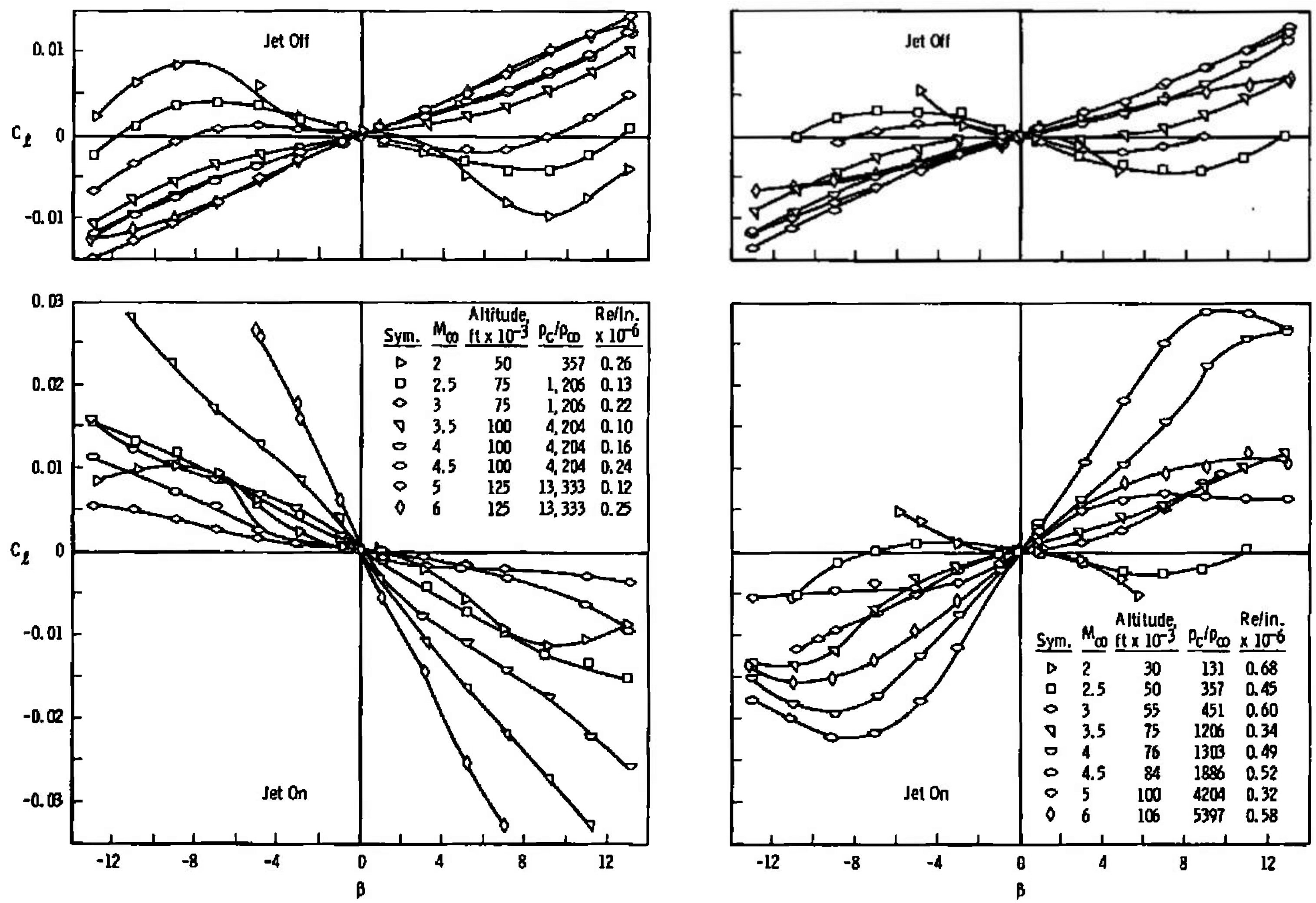
b. M_∞ = 4

Fig. 7 Continued



c. $M_\infty = 6$

Fig. 7 Concluded



a. Low Reynolds Number

b. High Reynolds Number

Fig. 8 Rolling-Moment Variation with Mach Number

TABLE I
TEST CONDITIONS

Nominal M_∞	Calibrated M_∞	p_o, psia	T_o, °F	p_∞, psia	Re/in. x 10^{-6}	Altitude, ft x 10^{-3}	p_c/p_∞		Configuration
1.5	1.47	5.91	100	1.682	0.145	50	0*	357	1, 2, and 3
1.5	1.48	19.45		5.454	0.470	25		101	1, 2, and 3
2	1.97	3.78		0.506	0.075	75		1,206	1
2	1.98	12.75		1.682	0.260	50		357	1, 2, and 3
2	1.99	33.60		4.365	0.680	30		131	
2.5	2.48	8.38		0.506	0.130	75		1,206	
2.5	2.49	28.3		1.682	0.450	50		357	
3	2.99	18.15		0.506	0.220	75		1,206	
3	3.00	48.9	100	1.330	0.600	55		451	
3.5	3.48	11.64	120	0.157	0.100	100		4,204	
3.5	3.49	38.0		0.506	0.340	75		1,206	
4	3.99	23.5		0.157	0.160	100		4,204	
4	4.00	71.0	120	0.468	0.485	76		1,303	1, 2, and 3
4.5	4.49	15.85	130	0.054	0.080	125		13,333	1 and 2
4.5	4.52	46.6		0.157	0.240	100		4,204	1, 2, and 3
4.5	4.53	100.0	130	0.333	0.522	84		1,886	
5	5.02	28.6	140	0.054	0.115	125		13,333	
5	5.02	85.0	160	0.157	0.325	100		4,204	
6	5.99	85.25	180	0.054	0.250	125		13,333	
6	6.00	199.0	180	0.126	0.580	106	0	5,397	1, 2, and 3

*Jet Off Condition

APPENDIX
JET PLUME SIMULATION

The procedure used to determine the model jet parameters for simulation of the escape rocket jet plume at various pressure-altitudes was as follows:

1. The basic method used was that outlined by Pindzola[1] for a jet exhausting into quiescent air. Retaining the nozzle divergence angle for the model and with the specific heat ratio (γ = 1.4) of the simulating fluid fixed, this method specified the model nozzle exit Mach number and chamber pressure ratio (p_c/p_∞) for the given full-scale rocket nozzle (Army XM-15) at a specific altitude (i.e., a given p_c/p_∞ since p_c = constant). Model scaling also fixed the nozzle exit diameter.

2. The desired test conditions covered several altitudes at each Mach number. Consequently, simulation was required for a wide range of p_c/p_∞ of the full-scale rocket. Obviously, it was not practical to provide a different model nozzle for each altitude condition; therefore, a compromise solution was sought which would allow the use of one nozzle configuration for all test conditions.

3. Using Pindzola's method, the model jet Mach number and chamber pressure ratio (p_c/p_∞) were calculated for each altitude. Then, selecting the mean value of these jet Mach numbers for the model nozzle Mach number, plume shapes were calculated for a wide range of p_c/p_∞ values including those obtained from the above calculation. Plume shapes were also calculated for the full-scale nozzle parameters for each altitude. The plume shape calculations were performed on an IBM 7074 computer using the characteristics method (perfect gas expansion in quiescent air).

4. Cross-plots were made of the model jet plume shape coordinates against p_c/p_∞ and, by comparison with the plume coordinates of the full-scale rocket nozzle, a range of p_c/p_∞ values was obtained

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[1]M. Pindzola. "Boundary Simulation Parameters for Under-expanded Jets in a Quiescent Atmosphere." AEDC-TR-65-6 (AD454770), January 1965.

which gave the desired plume shape matching at various locations along the plume axis for each altitude condition. Judicious selection from these values then gave a p_c/p_∞ value for each altitude which gave the best compromise fit at all axial locations along the plume axis.

5. Plume shapes were then calculated for these selected jet chamber pressure ratios, and excellent matching with the plume shape for the full-scale rocket parameters was obtained for each altitude condition, as can be seen in Fig. I-1. As a further check on the adequacy of the simulation, plume boundaries were calculated for the full-scale nozzle and model nozzle parameters for the jet exhausting into a supersonic stream. These solutions[2] were obtained on an IBM 7094 computer. The close matching obtained for enveloping flows of Mach numbers 1.5, 2, 4, and 6 is shown for a pressure altitude of 100,000 ft in Fig. I-2.

6. The pertinent parameters for the full-scale and model nozzles are shown in Fig. I-3. Model scale was 10 percent, and it can be seen that exit diameter and divergence angle are the only geometrical parameters retained in the model scaling.

---

[2]R. J. Prozan. "PMS Jet Wake Study Program LMSC External Flow Jet Wake Program." Lockheed Aircraft Corporation, LMSC 919901, October 9, 1961.

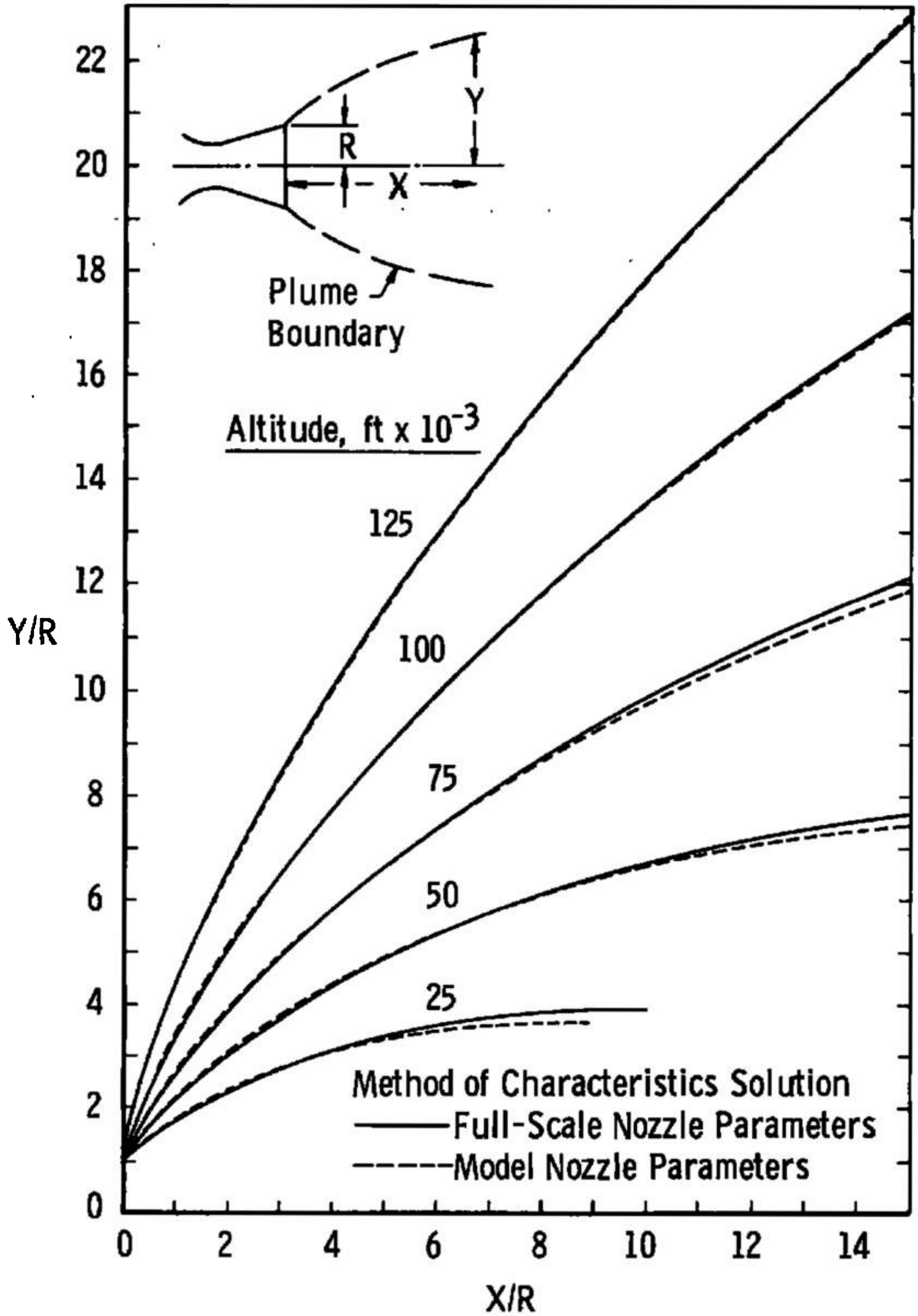


Fig. I-1 Jet Plume Simulation in Quiescent Air

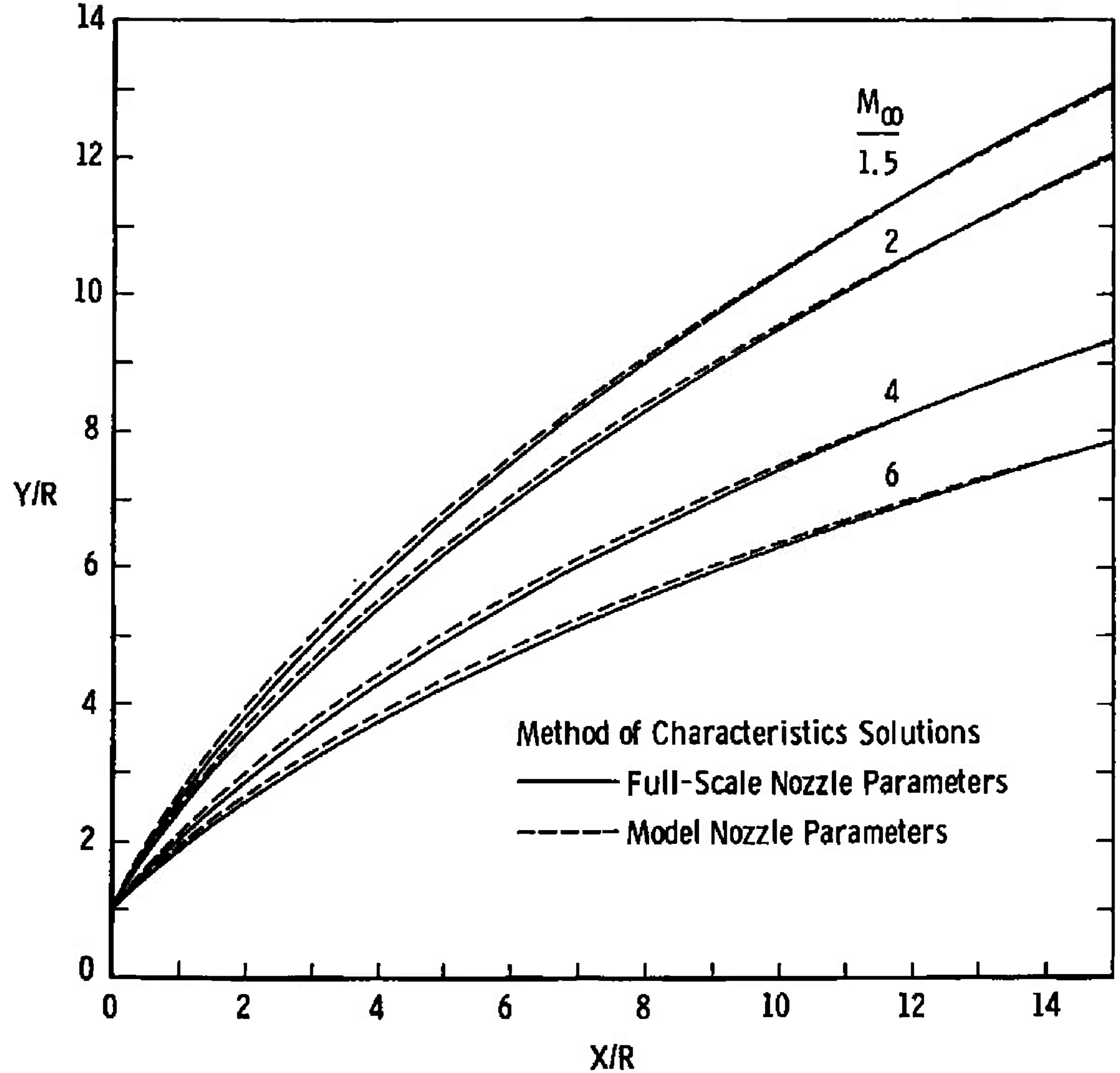
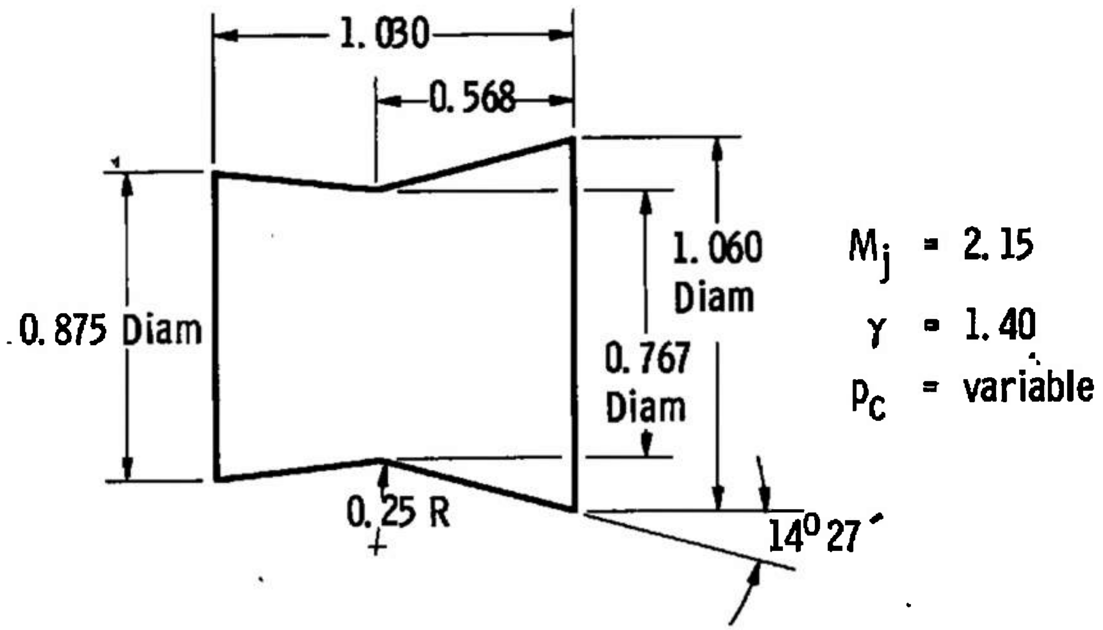


Fig. I-2 Jet Plume Simulation in a Supersonic Flow Field, Altitude = 100,000 ft



All Dimensions in Inches

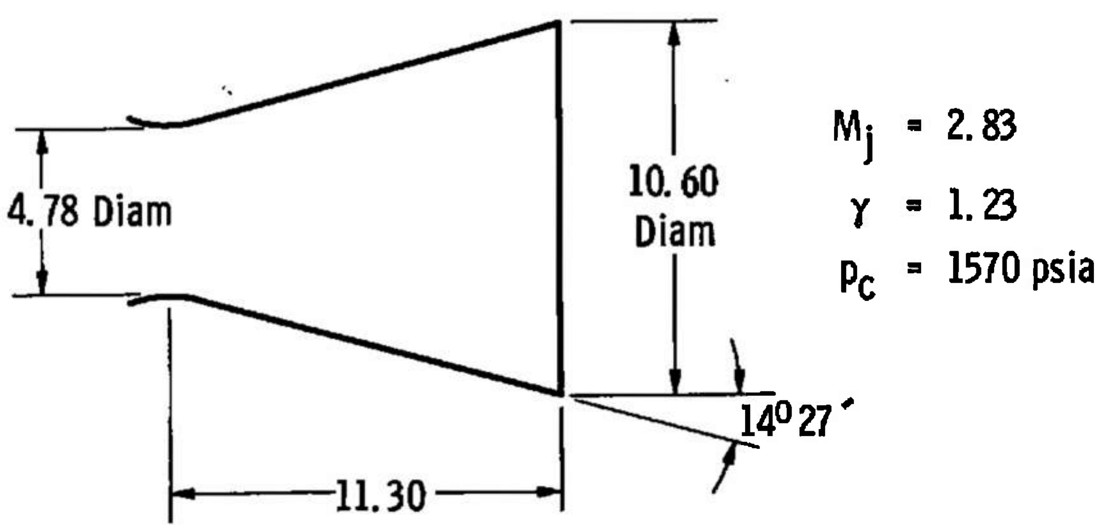


Fig. 1-3 Details of Nozzle Contours

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13 ABSTRACT

Static force tests were conducted in the 40-in. supersonic tunnel of the von Kármán Gas Dynamics Facility on a separable-nose crew escape capsule having cold flow simulation of the separation rocket jet plume. Data were obtained at Mach numbers from 1.5 to 6 at angles of attack from -30 to 30 deg and angles of sideslip from -15 to 15 deg. Reynolds number, based on a model length of 18.1 in., ranged from 1.36×10^6 to 12.3×10^6. Selected results are presented showing the effects of the rocket exhaust jet on the static stability and drag characteristics of the vehicle. (U)

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